RTD-TDR-63-1112

RESEARCH AND DEVELOPMENT OF AN AUTOMATIC BERYLLIUM-IN-AIR MONITOR

TECHNICAL DOCUMENTARY REPORT NO. RTD-TDR-63-1112

Rocket Propulsion Laboratory
Research and Technology Division
Air Force Systems Command
Edwards AFB, California

Project No. 3850, Task No. 38506

(Prepared under Contract No. AF 04(611)-7543
by the IIT Research Institute of
Illinois Institute of Technology;
Robert S. Braman, author)

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NOTICES

FOREWORD

This is Report No. IITRI 3203-5 (Final Report) Beryllium Monitor of IITRI Project C 203, Contract No. AF 04(611)-7543, AFPS No. 650A, AFSC Project No. 3850; and AFSC Task No. 38506, entitled "Research and Development of an Automatic Beryllium and Boron Monitor." This report covers only work accomplished on the beryllium monitor since a separate report (RTD-TDR-63-1072) has been issued on the boron monitor. This report covers all experimental work from 28 August 1962 to 17 June 1963.

Experiments were performed by S. Bernsen, A. Hansen, J. Haffner and R. Braman. The Air Force Project Engineers were Capt. R.J. Darby, Lt. J.F. Wakeman, and Lt. R.P. Couch of the Rocket Propulsion Laboratory, Edwards AFB, California

Data contained in this report are recorded in IITRI Log-books C 12872, C12994 and C 13385.

ABSTRACT

In improved model beryllium-in-air monitor has been constructed, calibrated and tested in the laboratory. Significant improvements include optimization of the air sample system design and elimination of the temperature instability of critical electronic parts. A concentration of 25 micrograms per cubic meter beryllium-in-air requires 4 minutes for reliable alarming, a low level concentration of 2μg beryllium requires 60 minutes. Sensitivity, alarm reliability and response time are all dependant primarily upon the construction of the alpha source. Other characteristics of the device and instrument design have been optimized.

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RESEARCH AND DEVELOPMENT OF AN AUTOMATIC BERYLLIUM-IN-AIR MONITOR

I. INTRODUCTION

The original specifications for the beryllium monitor called for an alarm at three levels: 25,2, and 0.01μg of beryllium per cubic meter over periods of 30 seconds, 1 hour, and 24 hours, respectively. A prototype beryllium-in-air monitor which is capable of alarming at the first two levels was developed. Because of dust loading and instrument sensitivity; it was found to be impractical to incorporate the 0.01μg alarm level into the instrument. The 0.01-μg alarm can be accomplished by wet-chemical analysis of Millipore filters which have filtered 100 cubic meters of air.

Only nuclear or spectrographic methods were found to be capable of providing an automatic analysis but because of difficulties in sample preparation and due to the required short response time, the nuclear was chosen over the spectrographic. The nuclear system uses the $Be^9(\alpha, n\gamma)C^{12}$ reaction which was made the detection method and was incorporated into the first prototype monitor."

Unfortunately the original prototype beryllium-in-air monitor had certain disadvantages, namely large size and weight, and temperature sensitivity of some of the electronic components. A development program was subsequently undertaken to eliminate the temperature dependency, to attempt to reduce the weight of the first proto-

type, to optimize its sample collection system, to simplify its operation and, if possible, to increase its sensitivity. Most of these goals were met. Unfortunately, sensitivity is still a major problem tied to difficulties of the radioactive source design. Details of the development program, method of calibration, operational characteristics of the second prototype monitor and a discussion of the alpha source problem are given below.

II. INSTRUMENTATION DEVELOPMENT

A. Nuclear Detection Technique

The reaction $Be^{9} + \alpha \longrightarrow N + \gamma + C^{12}$ is the basic method employed for the detection of beryllium. Design of both the first and second model prototype beryllium-in-air monitors was developed around the employment and detection of this nuclear reaction. The use of this nuclear technique requires the scrubbing of beryllia dust from air onto the surface of a tape for presentation to an alpha ray source. (See photographs, Appendix A). Beryllium-containing dust must be on the surface of the tape and close to the alpha source because alpha particles travel only a short distance in air and rapidly lose their energy.

Sensitivity of the nuclear reaction is the key factor in the design and operation of the beryllium monitor. Characteristics of the alpha source and the nuclear reaction influence sensitivity. These are: (a) background counting of gamma rays from the source itself, (b) the source window thickness, (c) the efficiency of detecting the nuclear reaction product and (d) specific activity of the alpha ray source per unit of area.

The detection of gamma rays was originally chosen because neutron detectors are at least 10 times less efficient than gamma ray detectors. Once gamma ray detection is selected, the problem of discriminating against the attendant gamma radiation of alpha ray sources arises. The gamma ray energy from the beryllium reaction is 4.5 mev, well above the energy of most attendant gamma radiation. Through the mechanism of gamma ray "pile up", however, a background gamma ray counting rate is very much in evidence (for

polonium-210 sources) even though discrimination is set to reject all energies below 4.0 mev. The gamma ray "pile up" observed is dependent upon both the energy and intensity of the attendent radiation and the amount of lead shielding employed between the reaction site and the scintillation counter.

Data obtained with the two polonium-210 sources, 3 curies activity each, furnishes some indication of the magnitude of the gamma "pile up" problem. Polonium-210 has a 10^{-3}% activity of 0.8 mev gamma rays relative to the total alpha activity. This caused a 150 counts per minute background counting rate in the finished beryllium-in-air monitor. The monitor had provision for discrimination against low energy gamma rays and lead shielding between detector and source. Six curies of polonium should produce 60 x 10^6, 0.8 mev gamma rays per minute in the direction of the detector. Discrimination achieved is therefore a factor of (150/60) x 10^6. The 150 counts per minute background is still undesirable since it contributes a statistical variation of $\pm$ 12 counts per minute to the overall counting rate. As will be seen later $\pm$ 12 counts is not an insignificant number in relation to the counts obtained when small amounts of beryllium are present. Alpha ray sources with lower energy attendent gamma radiation can be proposed (for example Pu-238). Plutonium-238 has 0.044 mev attendent gamma radiation and discrimination against this much lower energy radiation can be expected to produce a much lower background counting rate with the same techniques.

The third factor is the alpha ray energy and factors that affect it such as source window thickness. Most of the transuranium alpha ray emitters and polonium-210 have sufficiently high energy

alpha rays to give good reaction yields with beryllium. Interposing a window between the source and sample, however, decreases the specific activity of high energy alpha particles per source area. For polonium-210 sources, the window thickness has been found to be very critical. Three source window thicknesses have been experienced in the program. Table 1 gives the the pertinent data. The relative detectibility is a good indication of window thickness effect.

Table 1

CHARACTERISTICS OF POLONIUM-210 SOURCES

Window Thickness inches	Activity, curies	Area square inches	Counts/Minute 1 μ g Beryllium	Detectibility[a]
.00027	9	0.785	0.3	0.024
.00015	6	1.470	7.35	1.8
.00012	4	0.31	37	2.85

a. Counts per minute per curie per square inch.

The main reason for having a window over the alpha ray source is to prevent the creeping of radioactivity out of the source area. Thin windows of stainless steel foil are only a partial answer to the problem. The windows develop holes in a few weeks time; about 4 weeks has been average. It is apparent at the end of this development program that the source window problem is still not solved. Consequently, the best suggestion we can make is to initiate a program specifically for the development of a safe alpha ray source capable of giving sensitivity in the range of 30 to 60 counts per minute per microgram of beryllium present. The use of sources other than polonium-210 and the use of 2 inch diameter sources should be sought.

B. Sampling System

Once the sensitivity of the detection method has been established and the desired time constant chosen, the sampling rate required to collect the necessary amount of beryllium can be calculated. In order to improve sensitivity over that obtained with the first prototype monitor, a larger sample flow rate was required.

With the increased sample flow rate, it was necessary to provide a larger pump capacity and sample intake area. Consequently, a 2 in diameter sample intake was decided upon to provide the greater flow rate and to be compatible with the 2-1/2 in wide plastic tape chosen for dust collection. The plastic tape, obtained from Gellman Instrument Co., was found to be superior to the 1 inch wide reinforced Whatman tape used in the first model. The plastic tape develops an electric charge which electrostatically collects the fine particles on its surface and provides the conventional filtering action through small pore sizes.

Figure 1 shows the flow rate of the pump at various inlet vacuum ratings. The vacuum obtained with the 2 inch filter tape was approximately 7-1/2 inches of mercury. Consequently, the sample flow rate approximates 79 liters per minute. Using this flow rate it is easy to calculate the amount of beryllium collected on the tape under several conditions of concentration and in several time periods. Table 2 shows the results of these calculations. From Table 2 it is possible to predict the sen-

Table 2

BERYLLIUM COLLECTED ON A TAPE SAMPLER
UNDER VARIOUS DUST LOADINGS

Micrograms (Sample rate -79 liters per minute)

Sampling Period	Micrograms Beryllium per cubic meter			
	2	10	25	50
15 seconds	.04	.19	.49	0.99
30 seconds	.08	.39	0.99	1.98
1 minute	.16	.79	1.98	3.96
2 minutes	.32	1.58	3.96	7.92
3 minutes	.47	2.47	5.94	11.88
10 minutes	1.58	7.9	19.8	39.6

sitivity required to alarm at various beryllium concentration levels in selected time periods. For a one-minute time constant, for example (where a 1 minute time constant is defined as 30 sec. sample time plus 30 sec. counting time) at 25 micrograms per cubic meter, alarming requires a sensitivity of better than 1 microgram of beryllium since 1 microgram will be present on the tape. For alarming with a 2-minute time constant at 10 micrograms per cubic meter, 0.8 microgram of beryllium must be reliably detected. The consequence of the sampling rate at various sensitivities is discussed in later sections.

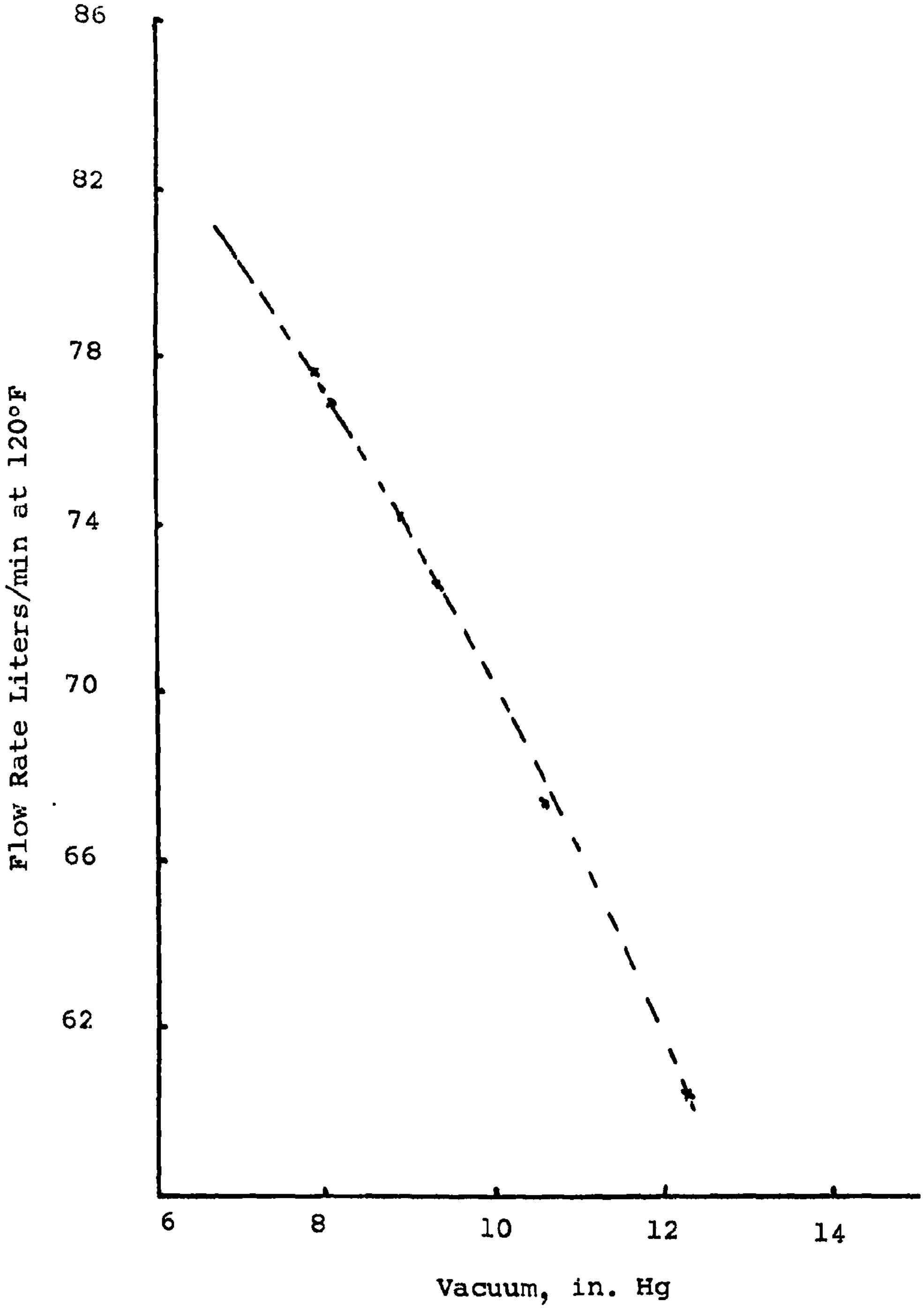


Figure 1 FLOW RATE OF SAMPLE AT VARIOUS PUMP PRESSURES

III ELECTRONICS AND ALARM CONSOLE

A. Operating Principles

The electrical portion of the beryllium monitor is made up of two functionally and physically separate portions. The first part is located in the field monitoring unit or sampling cabinet. Its function is to detect pulses from the scintillation detector and to pass on those which measure the beryllium present on the sampling filter. The second portion is the alarm and control console, and its function is to count the number of pulses received in predetermined time intervals, and to furnish an alarm signal if the number exceeds a predetermined value.

The first portion is shown in block diagram form in Figure 2, which also indicates the power supplies for the operation of the transistor electronics and the photomultiplier high voltage supply. Pulses from the detector are amplified and passed into a threshold device. This threshold triggers a pulse stretcher whenever input pulses exceed a predetermined level, as set by the threshold level and the amplifier gain. Since the threshold output is a short (one-fourth microsecond), low level pulse, the pulse stretcher is used to create from this pulse a longer, higher amplitude pulse more suitable for transmission to the console.

Connected to the field cabinet by a 300 foot cable is the control console. The block diagram for this portion of the electrical system is shown in Figure 3. Pulses arriving at the input to the console are fed to a pulse detector, another high level threshold device which produces an output pulse for every input

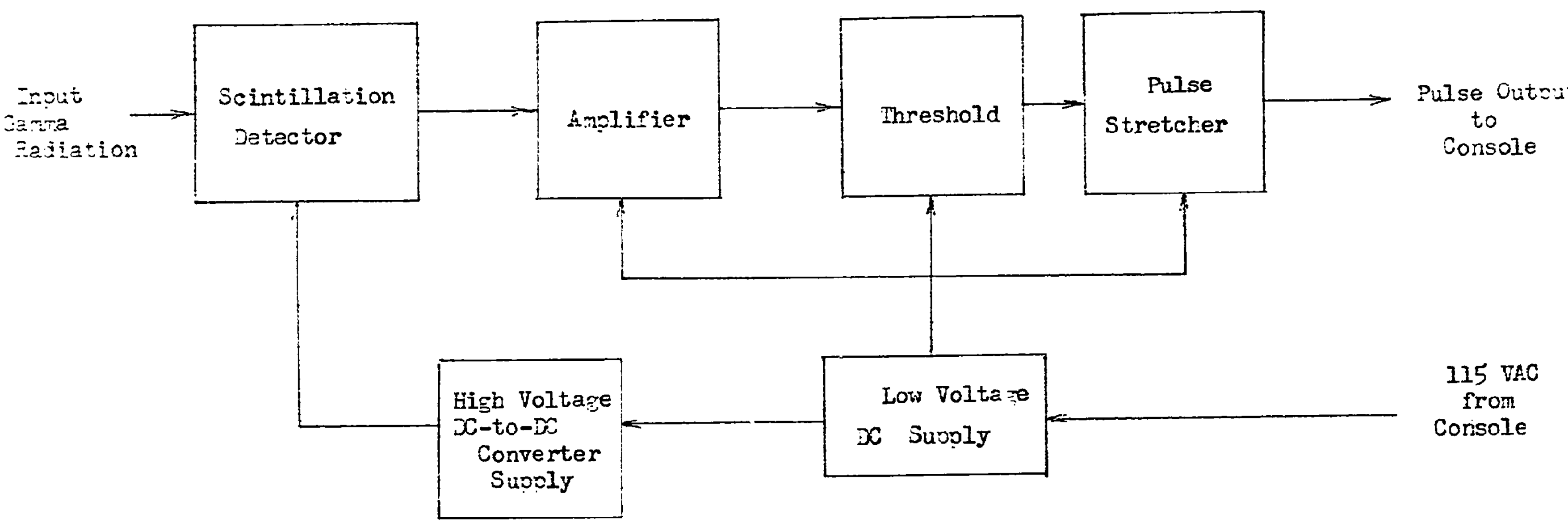


Fig. 2

<u>DETECTOR ELECTRONICS</u>

<u>BLOCK DIAGRAM</u>

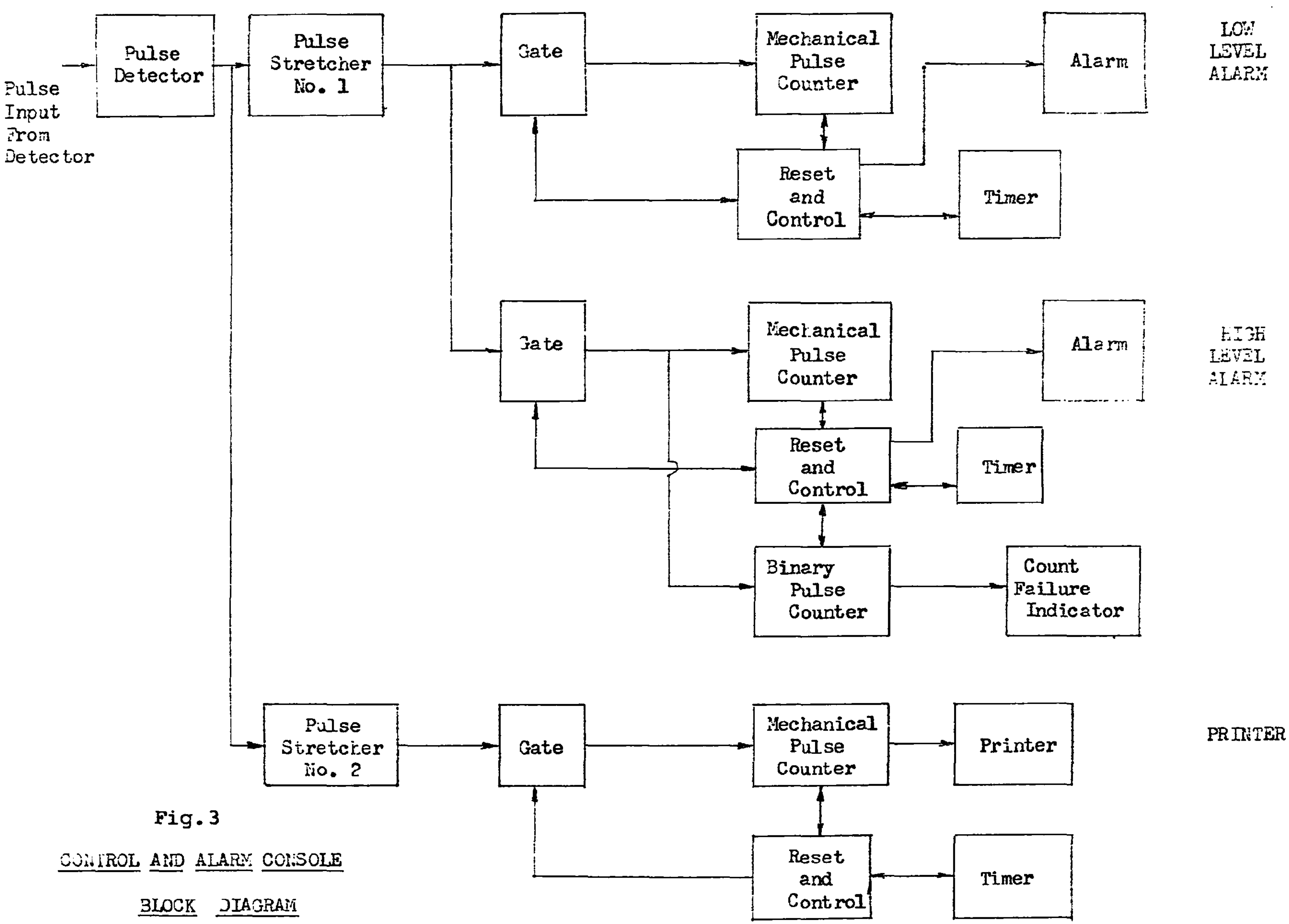


Fig. 3

CONTROL AND ALARM CONSOLE

BLOCK DIAGRAM

pulse exceeding a preset amplitude level. The threshold output is directed to two pulse stretchers. One of these provides an input to two parallel alarm and counting channels, and the other drives a counting and printing unit, operating independently of the counting alarm channels.

As stated previously, the function of the alarm channels is to provide a signal if the field sampling cabinent measures an excessive beryllium level. Two alarm levels are used. Each channel has a timer unit and a pulse counter. The pulse counter is initially set to a desired number of counts, and the timer is set to the corresponding time period. If the preset number of counts is exceeded in the preset time interval, then the alarm will sound. Each channel has resetting and control sections in addition to its counting, timing and alarming units. Since an alarm is given only when the input rate exceeds a predetermined level, the system is not "fail safe". For this reason, the short time, high level section of the alarm console has a "Count Failure Indicator". This section furnishes an additional output signal if, during any high level timing intervals, the high level alarm section receives no pulses. Since the field sampling cabinet is usually used at a location remote from the control console, this serves as a simple monitor to indicate a catastrophic malfunction of the sampling unit, as might be caused by a cable break, electronics failure or power supply short.

The printer unit is used simply as a data-gathering device, and operates independently of the alarm circuits.

B. Detector Electronics

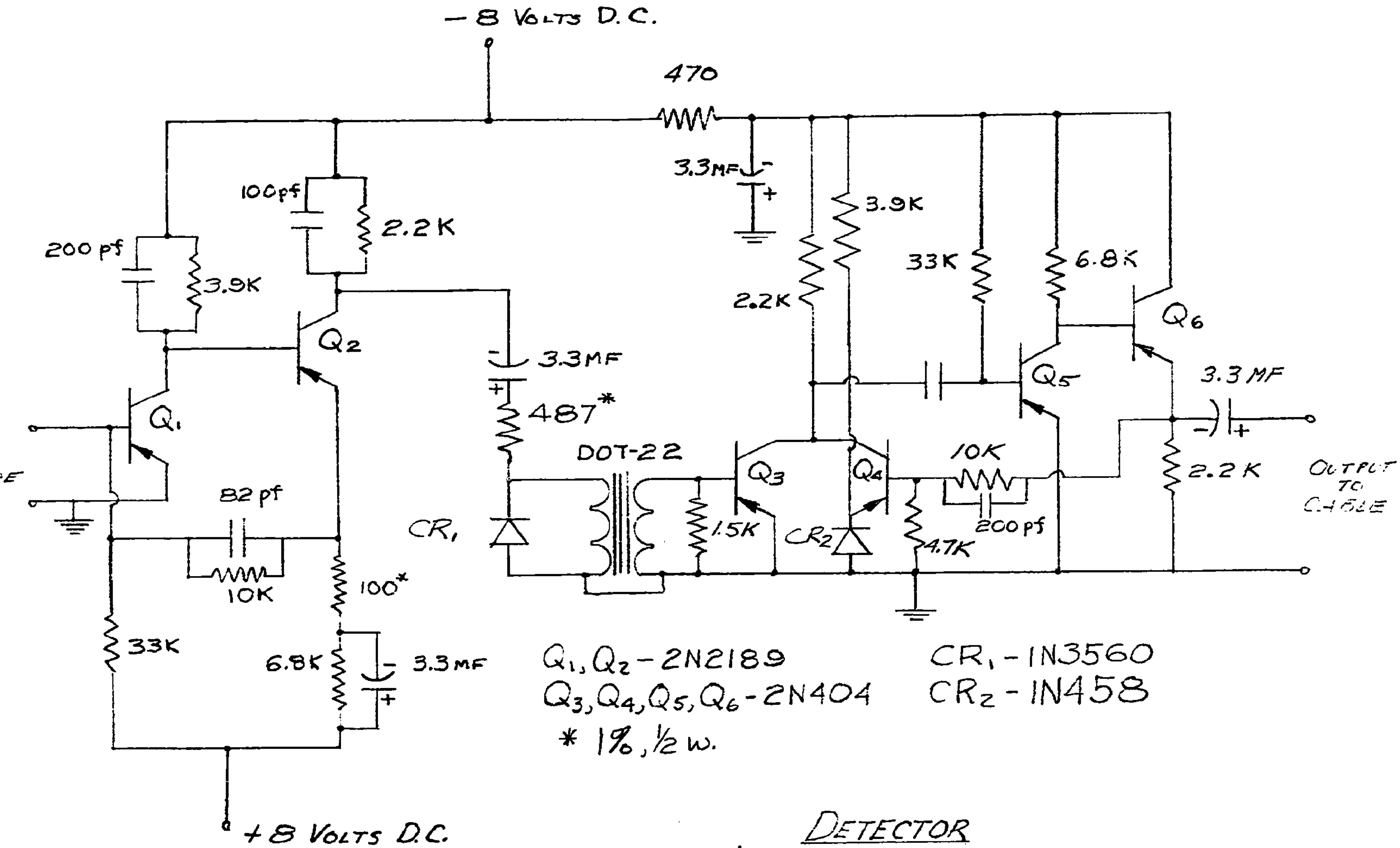
The sampling cabinet electronics system selects those pulses from the scintillation detector which measure the beryllium level at the sampling filter, and passes them on to the control and alarm console. The primary element in this electronics is the threshold detector. This is a tunnel diode which triggers a following stage if and only if the peak of a current pulse through the diode exceeds some fixed value. The pulses applied to the tunnel diode are of peak amplitude proportional to the energy level of the gamma input to the detector crystal, so an output pulse is produced every time there is an incident gamma greater than some preselected level. The scintillation crystal produces a light input to the photomultiplier tube in proportion to the incident gamma, and the photomultiplier tube converts the photon input into an electric current. This current is amplified again by the amplifier which drives the threshold device, in this case the tunnel diode.

The most important pulses from the photomultiplier tube are those corresponding to the gamma radiation of the beryllium reaction. These are at a high level, and are produced at a rate proportional to the intensity of the sample irradiation and the amount of beryllium present. If these were the only pulses present, it would be a simple matter to count all the pulses coming

from the detector and establish the beryllium level by this count. An important source of error, however, is the "background" count. At any setting of the threshold it is observed that even in the absence of all beryllium, output pulses are produced. Arising from a variety of sources, these background pulses tend to reduce the statistical confidence possible from a particular count rate.

The determination of that threshold level which most efficiently yields information as to the beryllium level in the presence of the background is done empirically, by measuring the count rate for various threshold settings both with and without beryllium. The result is two curves of count rate versus threshold setting. One curve is "background plus beryllium" and the second is "background". The ratio of these count rates is like a "signal-plus-noise to signal ratio", and the optimum threshold settings is that which maximizes this ratio.

The circuit schematic for the electronic amplifier, threshold, and pulse stretcher is given in Figure 4. The threshold element is a tunnel diode, with a peak current of 1.0 milliampere. For current pulses of peak amplitudes less than the diode peak current, the forward voltage across the diode never exceeds 0.05 volts. Any current in excess of this, however, causes the forward voltage to switch to approximately 0.5 volts, and to remain very close to this level until



DETECTOR
AMPLIFIER, THRESHOLD AND PULSE STRETCHER

FIG. 4

the current is almost zero. Thus, even current pulses which exceed the peak current for only a short time will produce a square-topped voltage across the transformer primary. This voltage is sufficient to switch the following stage, a conventional monostable multivibrator, into conduction for a time extablished by the circuit resistance and capacitance values. Thus, for tunnel diode current pulses with a peak value in excess of 1.0 milliamperes, the monostable multivibrator produces an output pulse of approximately 8 volts open circuit, lasting for twenty microseconds. This amplitude and duration is sufficient for dependable transmission down the cable connecting the sampling cabinet with the control console.

The input stage is a common-emitter, common-collector pair, with both AC and DC degeneration feedback from the output stage emitter to the input stage base. For slowly changing conditions the degeneration is extremely high. The large emitter resistor in the second stage develops a sizeable voltage due to emitter current, which voltage is fed back to the input stage base through a fixed resistor. This DC degeneration serves to stabilize the operating points of both transistor stages, thus contributing to open-loop gain stability by reducing current-dependent beta changes in both transistors.

For rapidly changing currents and voltages, operation is considerably different. Current into the base of the first transistor is multiplied by the high open-loop gain of the amplifier This produces a current change through the un-bypassed 100 ohm resistor in the emitter, of Q_2. The current fed back to the base of Q_1 is almost equal to the input current, and is proportional to the rate of change of voltage across the 82 pf feedback capacitor. If input and feedback currents are to be almost identical, then, for the rate of change of Q_2 emitter current to be proportional to the input current, the Q_2 emitter current must be proportional to the <u>integral</u> of the input current. Since the collector current of Q_2 is almost equal to the emitter current, the tunnel diode (CR) current is proportional to the integral of the input current, or is directly proportional to the integral of the input current, or is directly proportional to the input charge. Consequently, if the input charge is proportional to the energy of incident radiation in the scintillation crystal, the amplifier delivers to the tunnel diode a current whose peak value is proportional to the radiation energy.

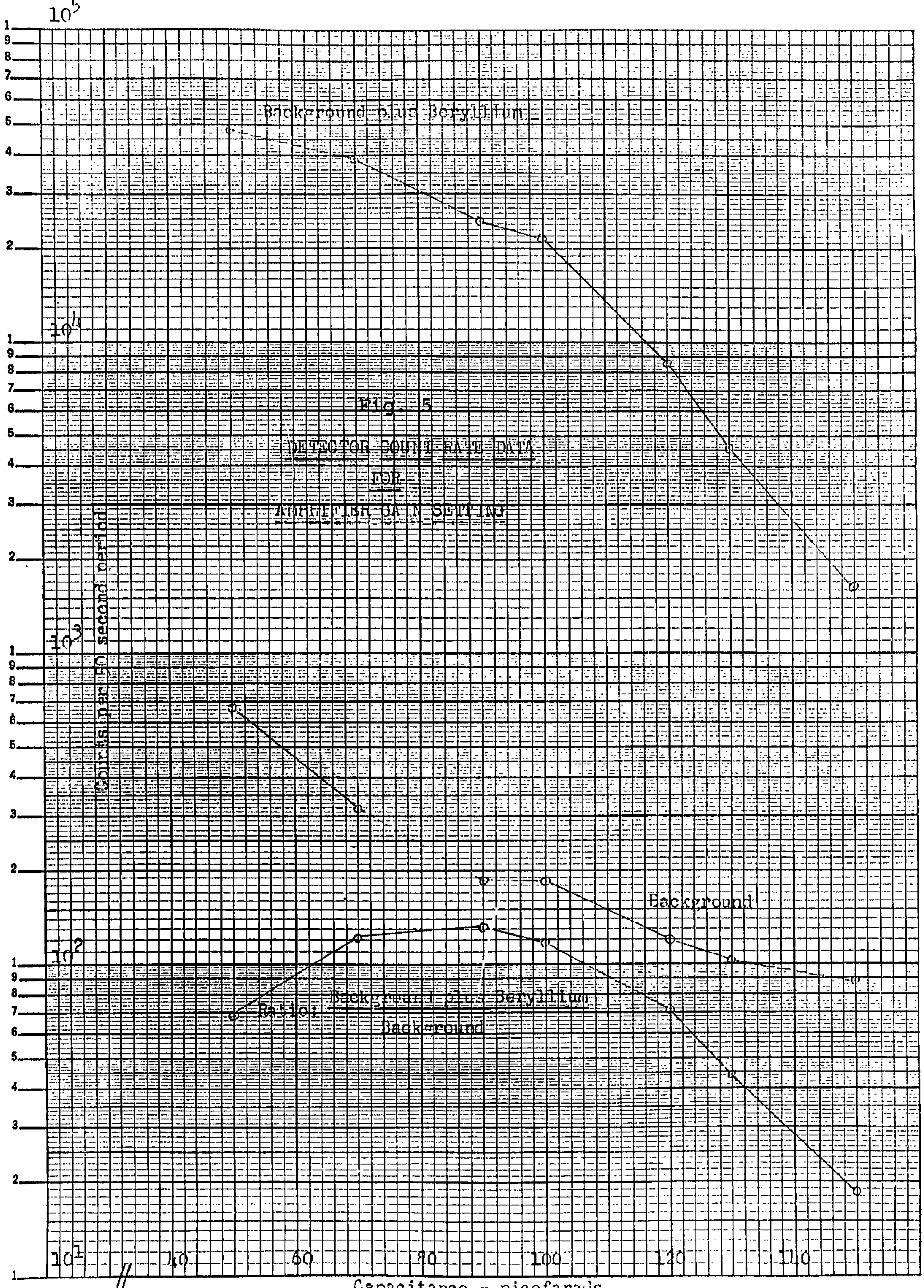
The transistors used in this circuit have a minimum beta of 60, so the open-loop current gain of the pair is high compared to the gain with feedback. To a good approximation, the gain is numerically equal to the product of the feedback resistor(100 ohms)

and feedback capacitor. The resistor is a stable, precision component, and the capacitor is a silvered-mica capacitor, so the gain is stable with temperature.

The complete electronics system was tested under elevated temperature conditions. A triangular input pulse was fed in to the input terminals through a 10,000 ohm resistor from a calibrated attenuator. The peak amplitude of the pulse was approximately 1.5 volts, and the "base" of the triangular pulse was one half microsecond long. This signal, using a 330 pf feedback capacitor, was sufficient to just trigger the threshold at a rate equal to the pulse input repitition rate, as measured by a pulse counter. Then the temperature of the test chamber was increased, and the attenuator set to the least setting which would provide enough signal for consistent triggering. By using this input rate-output rate comparison, attenuator setting sensitivity of the order of two parts per thousand was obtained. The temperature of the test chamber was varied from room temperature up to 155 degrees Fahrenheit in several steps, and returned to room ambient. The attenuator setting for consistent triggering was recorded as a function of temperature, thus providing an index of the amplifier-threshold gain change with temperature. It was noted that the gain decreased four percent from 80 to 100 Fahrenheit, and then increased slowly with temperature, reaching the original room temperature value at 155 degrees.

The gain of the transistor integrating amplifier (peak milliamperes per coulomb) determines the minimum energy level of

gamma radiation required to trigger the threshold. As discussed previously, the selection of an optimum triggering level is done empirically, by selection of a capacitor in the feedback path of the amplifier to yield an optimum "signal-to-background" ratio. For this equipment, the gain was determined by using an electronic pulse counter measure the number of output pulses in a period of 50 seconds. The two curves of "background plus beryllium" and "background" count rates versus feedback capacitor are given in Figure 5. It should be noted that the energy level for triggering is directly proportional to the feedback capacitance, since the threshold level is fixed. Data were not taken for very low energy levels, corresponding to capacitances below 30 pf, but the curves exhibit the expected shape. That is, the curve of "background count rate" versus energy level (capacitance) decreases with increasing capacitance. The curve of "background plus beryllium" count rate approaches the "background" count rate curve at either extreme. The ratio of the two count rates is given in a third curve, and it is seen that a rather broad maximum is reached near 80 pf. Since the slope of the curve does not change markedly with capacitance, it was felt sufficient to select the nearest standard capacitance value to 80 pf (82 pf) for the feedback capacitor. For this initial threshold setting (which is what the gain setting amounts to) no quantitative determination of the beryllium in the sample was made. This was not necessary since any amount of beryllium will produce pulses clustered about the same energy level, the only difference with quantity being the number of

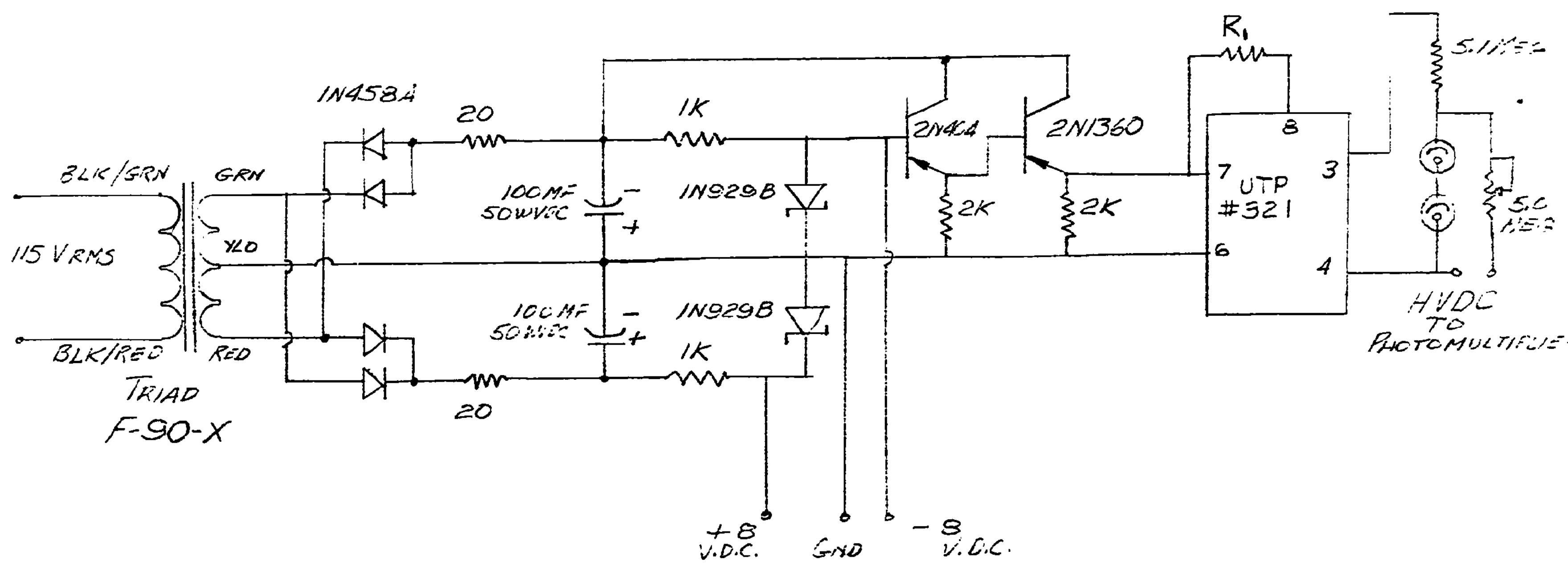

Background plus Beryllium
Fig. 5
DETECTOR COUNT RATE DATA
FOR
AMPLIFIER GAIN SETTING
Counts per 50 second period
Background
Ratio: Background plus Beryllium / Background
Capacitance - picofarads

pulses. The shape of the curve will remain relatively the same.

The power supply schematic is given in Figure 6. Conventional zener diode regulators furnish negative and positive supply voltages to the transistor circuitry. In addition, one of these voltages is used as a reference for a second low voltage supply which is used to power the photomultiplier high voltage supply. This high voltage supply is a packaged blocking-oscillator DC-to-DC converter. The output voltage of this supply is set by the input voltage and an external resistor. Since the high voltage supply has an output impedance of the order of ten megohms, the output is rather more like a current than a voltage. Corona regulator tubes are used to set the output level. With fixed input voltage and external resistor and with the low current drain of the photomultiplier tube, the current drain on the supply remains essentially constant. With the first Harshaw detector used, an output voltage of 1500 volts was found (the maximum) necessary for sufficient output, so a 700 and 800 volt regulator tubes were used in series to provide this as an upper limit. A series resistor was provided to make fine adjustments in the high voltage output. Since the current drain of the tube is almost entirely in the resistive voltage divider for the dynodes, good voltage stability was obtained.

The original supply voltage maximum of 1500 volts was chosen on the assumption that the first detector crystal-tube combination used was one of maximum sensitivity. From considerations of the permited manufacturing variations in photomultiplier sensitivity and multiplications, it was calculated that the necessary range of supply voltages to accomodate all possible tubes would be in

NOTE: SELECT R_L FOR DESIRED UTP-321 TERMINAL VOLTAGE



DETECTOR ELECTRONICS
POWER SUPPLY

FIG. 6

the range from 1250 to 1450 volts, since the tube multiplication varies approximately as the six or seventh power of supply voltage. The actual Harshaw detector employed in the unit had sufficient sensitivity, so a supply voltage of only 800 volts was required. This was done by readjusting the high voltage supply external resistor and shortcircuiting the 700 volt regulator tube. The tube is connected directly across the 800 volt regulator tube. Should it ever become necessary to replace the Harshaw detector, it may be necessary to adjust the supply voltage for the proper value. Consequently, the capacity for increased supply voltage was retained.

C. Control and Alarm Console

The control and alarm console measures the average rate of beryllium detector output pulses, and signals if the rate exceeds either of two preset levels. The console has a control and alarm section, with two parallel channels for counting the timing pulse rates. In addition, an electromechanical printer and counter unit is provided as an aid in continuous monitoring of beryllium levels below the alarm rate. The console is completely automatic in operation, requiring no attention from the operator once the initial settings of count and time criteria have been made

Since maximum reliability at lowest cost was the objective of the console design, extensive use was made of "off-the-shelf" components. In order to increase maintainability, plug-in-construction was used exclusively, and any components subject to failure can be replaced readily.

Since the actual wiring of the console is covered in the Operating Manual, wiring and schematic diagrams are not included in this report. Of primary interest is the logic of the switching, timing and alarming circuits, since the logic is determined by the operating requirements and the constraints of the equipment employed.

Operating Requirements

a. Input - The input to the console consists of the pulses from the sampling and detector unit. The average rate of these pulses is the measure of the beryllium concentration.

b. Output - An alarm is to be given if, in some preset time interval, the number of input pulses accumulated exceeds a preset number.

c. Count Failure - An alarm is to be given if, in one of the preset time intervals, no pulses are counted.

Equipment Constraints

The primary equipment constraint was in the electromechanical pulse counter. The design of this counter requires that, during the period when it is being reset to zero, no pulses shall be counted. (This is to prevent damage to the mechanical assembly.)

The secondary restraint was in the timer unit. This unit requires a contact closure to initiate the timing period.

From the requirements and constraints above, the switching logic of the control system could be outlined. Since dependability was of paramount importance, it was decided to use heavy-duty industrial type switching transistor logic units. The type selected,

Del-Con controls by Delco Division of General Motors, were primarily designed for machine and process control application and the variety of plug-in modules available made for an extremely flexible design. Further, since the interconnections were by taper pin lead wires, replacement of units in the field should be a relatively simple matter.

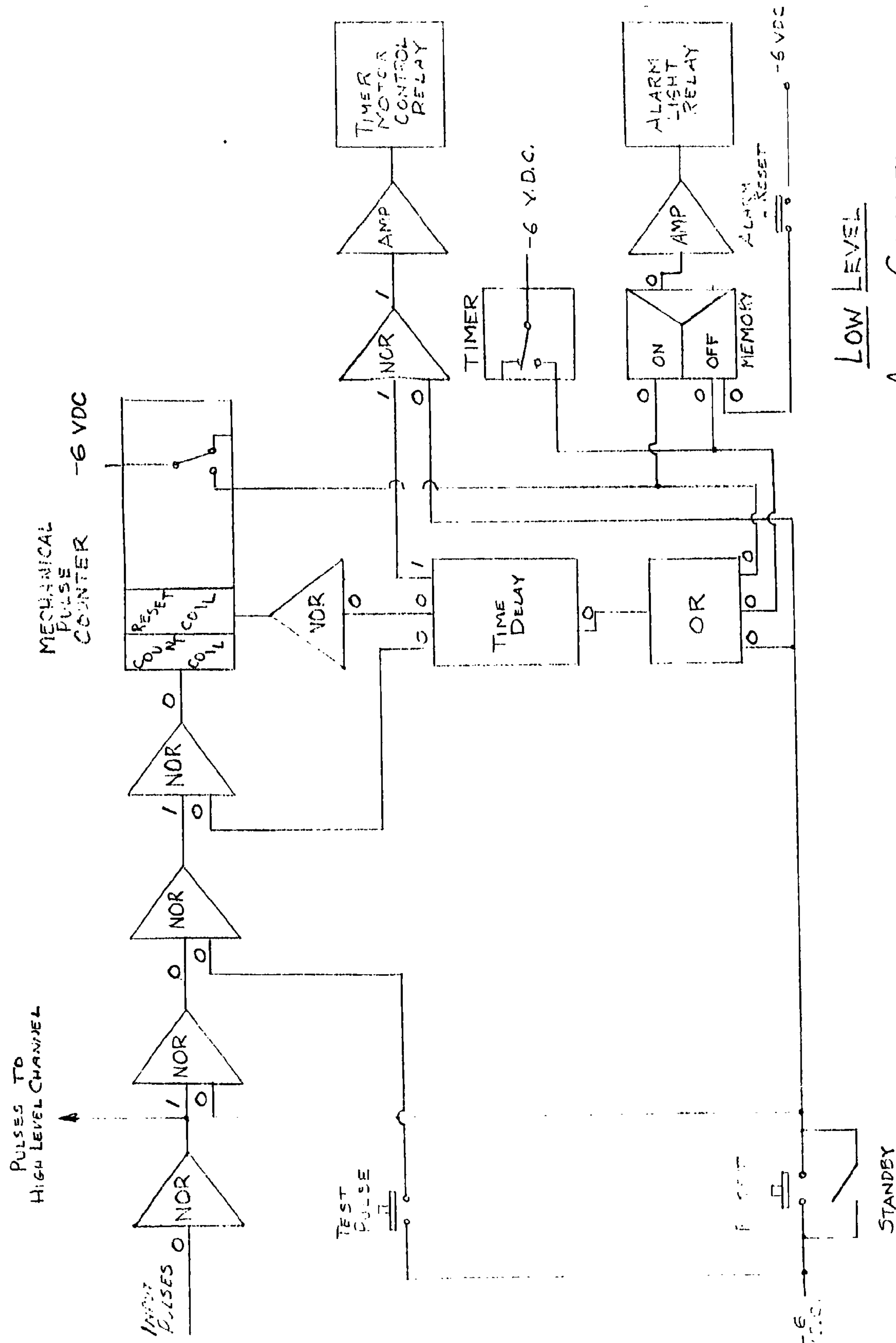
The basic unit in the control switching section is the logical NOR unit. This has the property that a logical "one" (negative six volts) is present at the output if and only if all of the inputs are logical "zeroes" (zero voltage). The timer unit produces a logical "one" for a predetermined time after a logical "one" is applied to its input. The Memory unit is bistable. It has two output terminals, which must be logical complements of each other. Depending upon the prior state of the unit (that is, which particular output terminal is at "one") an input "one" applied to one of the input terminals will cause both outputs to switch to the other state. Continued application of "ones" to the same input terminal will have no effect upon the output. A "one" applied to the other input side will cause a reversal. "Ones" applied alternately to one input terminal and then the other will cause the output terminals to alternate. The unit is called a "memory" because the effect of an input pulse depends upon the previous histroy of the unit.

Another unit is the Power NOR. This is a solenoid driver, which furnishes the driving current to the counting and resetting coils of the counting register. "Amplifier" units serve the

function of relay drivers. Conventional 24-volt relays are used to switch the timer motor and the alarm lights.

Consider the low-level alarm channel of Figure 7. The counter coils are connected to Power NORs, and a switch is arranged to provide a logical "one" if the counter receives sufficient pulses to count down from a preset number to zero. The timer is arranged so that it operates whenever the relay in its motor circuit is closed. The timer also has an output switch, which provides a logical "one" when the timer has completed its cycle. As input pulses arrive, they successively drive the counter towards zero count, as the timer runs to the end of its set time interval. Eventually, either the timer must complete its cycle before the preset number of pulses is received, or the counter must count down to zero before the timing cycle is completed. The first case indicates a less-than-critical count rate, while the second case indicates a cause for alarm.

Either event initiates a reset cycle. During this cycle, the timer produces a resetting pulse to the reset coil Power NOR, and also a logical "one" which effectively blocks input pulses from the counting coil Power NOR. Further, the timer motor relay opens the timer motor circuit, which automatically resets the timer to the beginning of its timing period. At the end of the reset time, the count blocking signal is removed and the timer is permitted to resume its cycle. Since the "count-to-zero" pulse and the "time-to-zero" pulse cannot both occur, one of these is applied to its own side of the "alarm memory". This memory controls the alarm relay. Thus, regardless of the prior



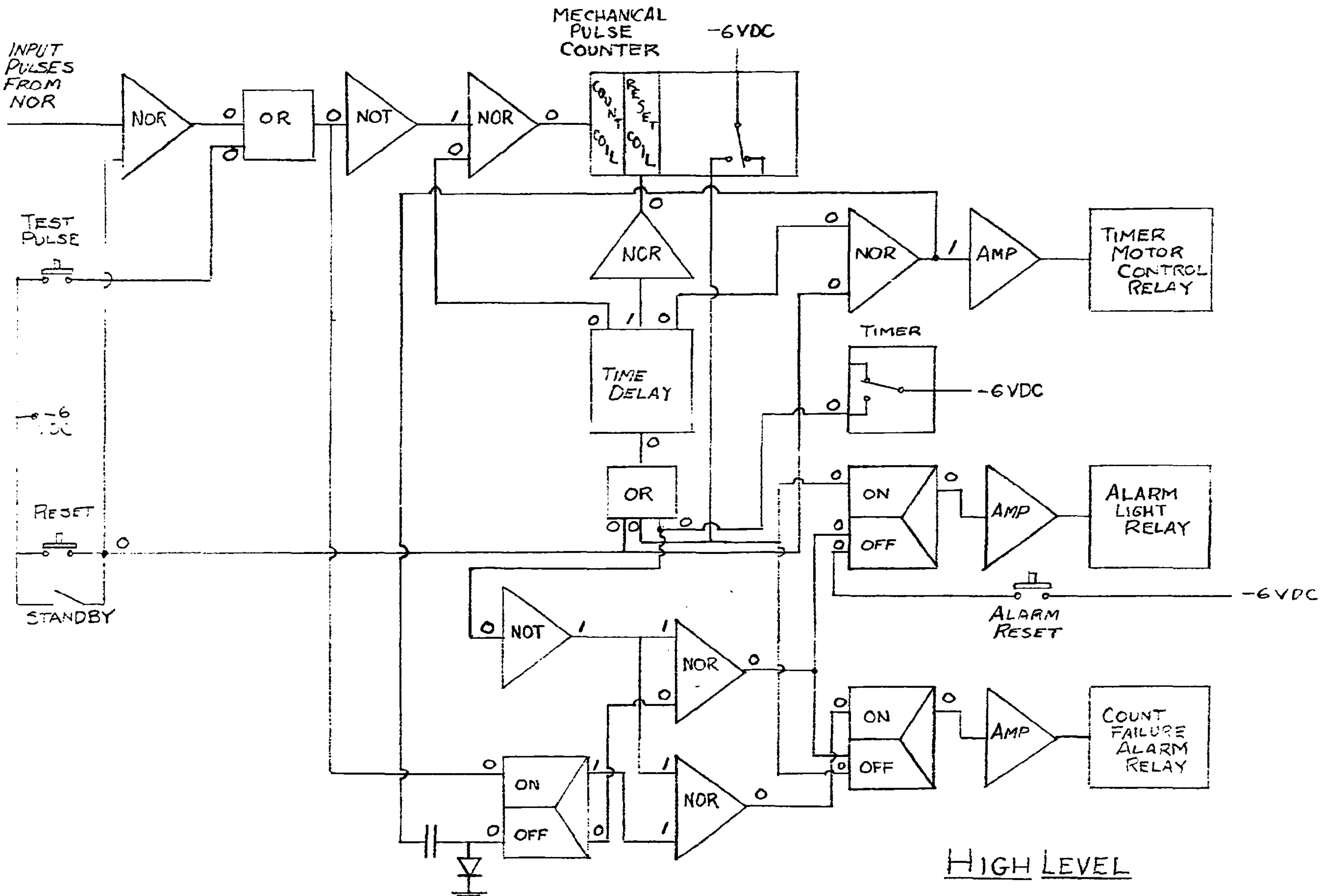
LOW LEVEL ALARM CHANNEL

FIG. 7

state of the memory, the relay contacts are set to the proper state.

The high-level alarm channel is shown in Figure 8. This is identical to the low-level channel except for the "count failure" portion. In this, a memory device is used as a simple pulse counter which can count only to one. The logic of this circuit is based upon the premise that, if the counter counts down to zero and thus initiates a timing cycle, there must have been at least one pulse received during the period. If the timer times to zero, however, this may be due to having received only a few pulses, less than the critical number, or to having received none at all. Note that the outputs of the simple pulse counter must be complementary, and that each is connected to a NOR unit. The timer pulse (in this case, a logical zero) arrives at the input to both NORS, but can pass through only that one which receives a "zero" from the memory. Thus, if the pulse counting memory had not received a pulse in the previous time interval, the count failure memory would be triggered to the "count failure" output, and the appropriate indication made. Note also, that if the alarm memory had been in the "alarm" state, the absence of pulses during a timing interval would prevent the timer output from resetting the alarm to "safe".

By means of a pushbutton, test pulses can be inserted into either or both channels to check out the unit if trouble is suspected. Additional controls are provided so that either or both channels can be independently reset, or placed on "standby". When a channel is placed on "standby" a red neon indicator is



HIGH LEVEL
ALARM CHANNEL

FIG. 8

turned on. This is to prevent the unit being accidentally kept on "standby" and indicating "safe" although a "safe" condition may not actually be monitored. An "alarm reset" pushbutton is provided so that during tests the alarm channel can be switched from "alarm" to "safe". Note that this does not disable the alarm, since the next "count-to-zero" pulse will switch the alarm memory and turn the alarm indicator back to "alarm".

IV. CALIBRATION

Calibration of the beryllium monitor was achieved by analyzing tape samples chamically after establishing their counting rate. Ten percent beryllium oxide in Arizona Road Dust were used in the apparatus shown in Figure 9 to generate a beryllium-containing dust to be analyzed by the monitor. Several tape collected samples were analyzed for beryllium activity by the monitor and then analyzed chamically for beryllium content. Counting rate data for the various samples and background are given in Table 3. Figure 10 shows a plot of the calibration curve. Linearity is excellent. The procedure for analyzing the plastic filter tape follows.

A one inch wide piece was cut out of the center of the two inch diameter sample intake. This piece contained the beryllium in the tape areas under the one-inch wide sources. Tape samples were folded and dry ashed in covered platinum crucibles. The residue was treated with 1/2-1 ml of 48% hydrofluoric acid and a few drops of concentrated sulfuric acid. Fumes of hydrofluoric acid and sulfuric acid were expelled by careful heating on a hot plate. Most of the sulfuric acid should be romoved to simplify neutralization. The residues were transferred to 10 ml volumetric flasks from which 2 and 5 ml aliquots were taken depending upon the beryllium concentration range of the sample. Sample aliquots were added to 100 ml beakers. To these were added 4 ml of 6% EDTA, 5 ml of sodium acetate (50 g/liter), 5 ml of Eroichrome Cyanine R dye (0.9 g dye in 250 ml water,

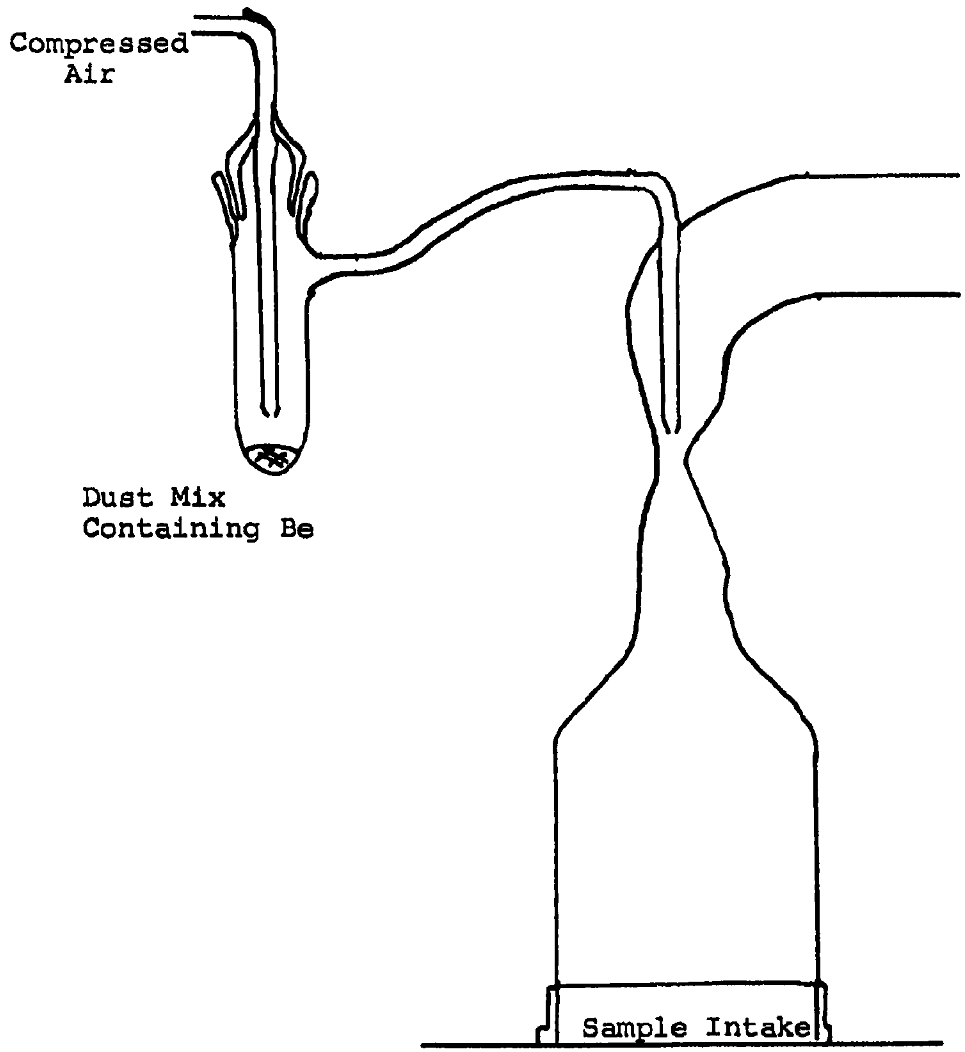


Figure 9

Apparatus for Generating a Test Dust Aerosol

Table 3

COUNTING RATE DATA - CALIBRATION
WITH 2 - 3 CURIE SOURCES

Beryllium[a] Oxide Present	Average Counts/2 minutes	No. of Observations	Be counts Net counts/ 2 minutes
None	316.3	12	-
None	325.8	5	-
87.0 μg	1011	4	690
44.6 μg	675	4	354
69.8 μg	843	4	522
None	309	3	-
5.0 μg	341	3	34

[a] Beryllium on 1 inch wide section of tape area directly under sources.

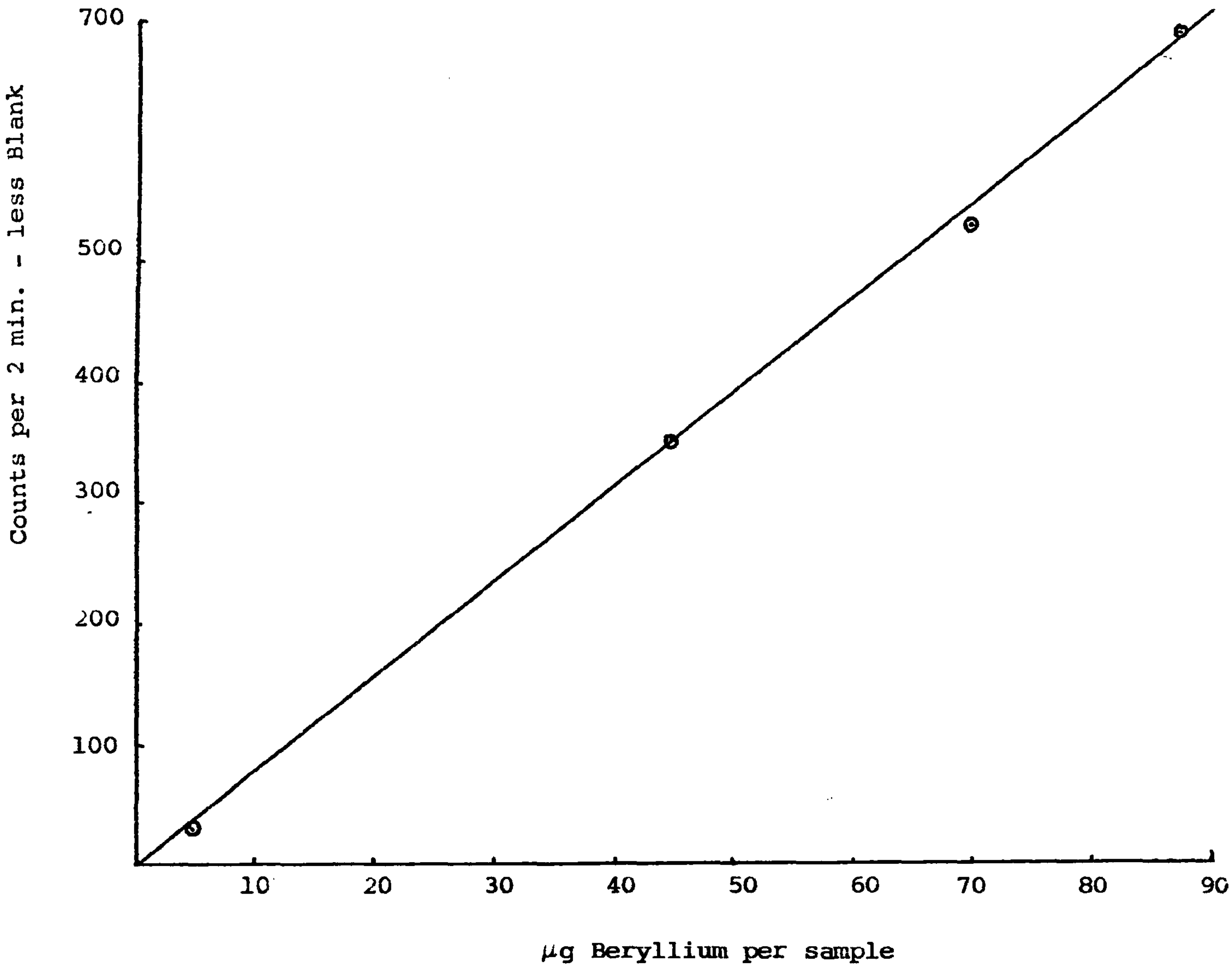


Figure 10

Calibration Curve for the Beryllium Monitor
2 - 3 Curie Sources

25 g sodium chloride, 25 g ammonium nitrate, 2 ml nitric acid, and 100 ml of 95% ethanol - the entire mixture diluted to 1 liter with water). The pH of the solution was adjusted to 9.7-9.8 with sodium hydroxide. The solutions were transferred to 50ml volumetric flasks and diluted to the mark. Absorbancy readings against a reagent blank were made in 1 or 2 cm cells at 515 millimicrons after 30 minutes. A blank reading for the tape was determined and subtracted from all sample results. The calibration procedure was comparatively easy to employ and required only about one day to perform including the blank and standard analyses.

V. OPERATIONAL CHARACTERISTICS

Sample flow rate, sensitivity, and background counting rate combine to govern the concentration levels detectible in various periods of time. These factors can be combined in several equations. The count recorded in a single sampling period, C_t, is a function of background counting rate, sample flow rate and others.

$$Ct = (N_o)\ (t) + \ (f)\ (C)\ (N)\ (t)\ (A_s) \qquad (1)$$

where N_o is the background counting rate expressed in counts per minute, N is the counting rate of the sources due to beryllium alone expressed in counts per microgram of beryllium per minute, f is the sample flow rate in liters per minute, C is the concentration of beryllium in micrograms per cubic meter and A_s is the fraction of the sample type area analyzed in determining the sensitivity of the sources. Note that the analysis time t (min) is the same as the sample collection time. The factor N in equation 1 should be determined by analyzing only the sample tape area under the sources. If the total sample area is analyzed, the factor A_s drops out. A uniform distribution of beryllium on the sample tape is assumed. The net counting rate due to beryllium alone is

$$C_{Be} = C_t - (N_o)\ (t) \qquad (2)$$

When data are stored in the long term count circuit the total

count, C_t, is obtained as a multiple, μ, of a single counting period.

$$C_t = (n)\ (C_T) \tag{3}$$

Precision can be estimated by taking the square root of the total counts in each case. Since the background counting rate is not zero or much smaller than the counting rate due to one microgram of beryllium its standard deviation seriously affects the sensitivity of the method and the precision with which the alarms actuate.

Typical data can be calculated utilizing the above equations for the beryllium monitor. The sample flow rate of the beryllium monitor is 79 liters per minute through the two inch diameter sample tape area. Table 4 shows the counting rates obtainable in various sample collection periods at the desired alarm concentration level of 25 micrograms beryllium per cubic meter.

It is apparent from the data that longer sample collection periods than 30 seconds will be required to give reliable alarms at 25 micrograms per cubic meter.

Table 5 shows the counting data obtained in various time periods for the case of 2 micrograms of beryllium per cubic meter. It is apparent from these calculations that longer sampling periods will be required for more reliable alarming at the 2 μg beryllium per cubic meter concentration level.

Table 4

COUNTING RATES AT 25 μg BERYLLIUM PER CUBIC METER

A. 2-3 Curie Sources

Sample Collection Periods	Total Be[a] Present	C_t Counts/min	C_{Be} Counts/min	$\sqrt{C_t}/C_{Be}$ [b]
Seconds	μg			
15	0.49	161	3	13/3
30	0.99	164	6	13/6
60	1.98	170	12	13/12
120	3.95	182	24	13/24
240	7.90	206	48	14/48

B. Estimation for 1-2 in diameter 6 Curie Source

Sample Collection Periods	Total Be Present	C_t Counts/min	C_{Be} Counts/min	$\sqrt{C_t}/C_{Be}$
Seconds	μg			
15	0.49	163	5.4	13/5.4
30	0.99	169	10.8	13/10/8
60	1.98	180	21.6	13/21.6
120	3.95	201	43.2	14/43
240	7.90	244	86.4	16/86.4

[a]The sources observe only 55% of the total beryllium.

[b]Related to standard deviation of beryllium analysis.

Table 5

COUNTING DATA AT 2 μg BERYLLIUM PER CUBIC METER

A. 2-3 Curie Sources
30 minutes alarm

Sample Collection Period	Total Be Present	C_t 30 min	Beryllium Counts/30 min	$\sqrt{C_t}$
Seconds	μg			
15	0.04	4740	7.2	69
30	.08	4754	14.3	69
60	.16	4769	28.6	69
120	.32	4797	57	69
240	0.64	4854	114	70
600	1.58	5006	266	71

B. 2-3 Curie Sources
60 minutes alarm

Sample Collection Period	Total Present	C_t 60 min	Beryllium Counts/60 min	$\sqrt{C_t}$
Seconds	μg			
15	0.04	9494	14.4	97
30	.08	9509	28.5	97
60	.16	9537	57.0	97
120	.32	9594	114	98
240	0.64	9708	228	98
600	1.58	10012	532	100

Beryllium counting rate data for a 2 inch diameter 6-curie source will be approximately 80% greater than shown.

In view of the data obtained it is recommended that for two 3-curie sources the beryllium monitor be set with the following operating conditions:

sampling period	2 minutes
response time	4 minutes
low level alarm	9594 counts
high level alarm	364
low level clock	60 minutes
high level clock	2 minutes
recorder period	20 minutes
low level blank	9480 counts
high level blank	316 counts

The standard deviation of the high level alarm count is 40% of the beryllium count under these conditions. This means that the alarm is set at more than 2 standard deviations higher than the standard deviation of the blank counting rate. The standard deviation of the low level alarm count is 86% of the beryllium count at 2 μg per cubic meter. The alarm is therefore set just over one standard deviation higher than the background count. Alarming reliability is therefore less than for the high level alarm. If the long term alarm is desired at 4 micrograms beryllium per cubic meter, the following settings should be used.

sampling period	2 minutes
response time	4 minutes
low level alarm	9708 counts
low level blank	9480 counts
low level clock	60 minutes

The standard deviation of the low level alarm count is now only 43% of the beryllium count and reliability is considerably improved.

Similar calculations can be made using a 2 inch diameter source, 6 curies of activity. The beryllium count will be 80% higher than given above and the sensitivity improvement can be used to decrease response time or to improve alarm reliability. An increase in source size or a decrease in background counting rate will also improve sensitivity and reliability.

The most urgent recommendation in the operation of the monitor is to use sample periods of at least one minute or longer even if higher sensitivity sources can be designed. This will save on the cost of tape and replacement frequency by at least a factor of 4. The response time of 30 seconds does not appear to be warranted in practical cases when the beryllium concentration is expected to go above 25 micrograms per cubic meter.

The original target specification of alarming in 30 seconds when 25 micrograms of beryllium is present was not met by the monitor. The main reason for this is the considerably decreased sensitivity of the sources obtained for the present device.

Nearly all other specifications have been met however. The beryllium monitor is quite versatile. A variety of response times and alarm levels can be set. The operating parameters can easily be calculated from sensitivity data as has been done in this report.

The electronic design should now be considered optimum since temperature stability has been designed into the instrument. The sampling system is also optimum since larger sized sample air intake orfices would complicate alpha source construction and smaller orfices restrict sample size. The Model II beryllium in air monitor is also designed for easy replacement of parts through the use of logic modules and packaged components.

VI. COST ESTIMATE FOR VOLUME MANUFACTURE

The total parts cost of the beryllium in air monitor was $5000. The manufacture of 10 units is therefore estimated to be $50,000 plus labor cost of approximately $30,000 with a 20 to 30% cost reduction for lots of 100. These estimates include $1400 for two sources for each instrument.

Appendix A

Photographs of the Beryllium-in-air-monitor.

Photo No.	Description
11	Overall view of the console module showing the control panel, register panel.
12	Close-up view of the alarm panel.
13	Back view of the console module.
14	Front view of the field module showing the tape drive mechanism, scintillation detector and source location (front cover removed).
15	Side view of the field module showing the power and signal connectors and blower.
16	Back view of the field module showing the sampling pump tape drive mechanism, and power supply-discriminator box. An air filter is on the right side of the module (back cover removed).
17	Back view of the field module with the electronic package removed.
18	Inside view of the electronic package in the field module; High voltage power supply and pulse height discriminator.

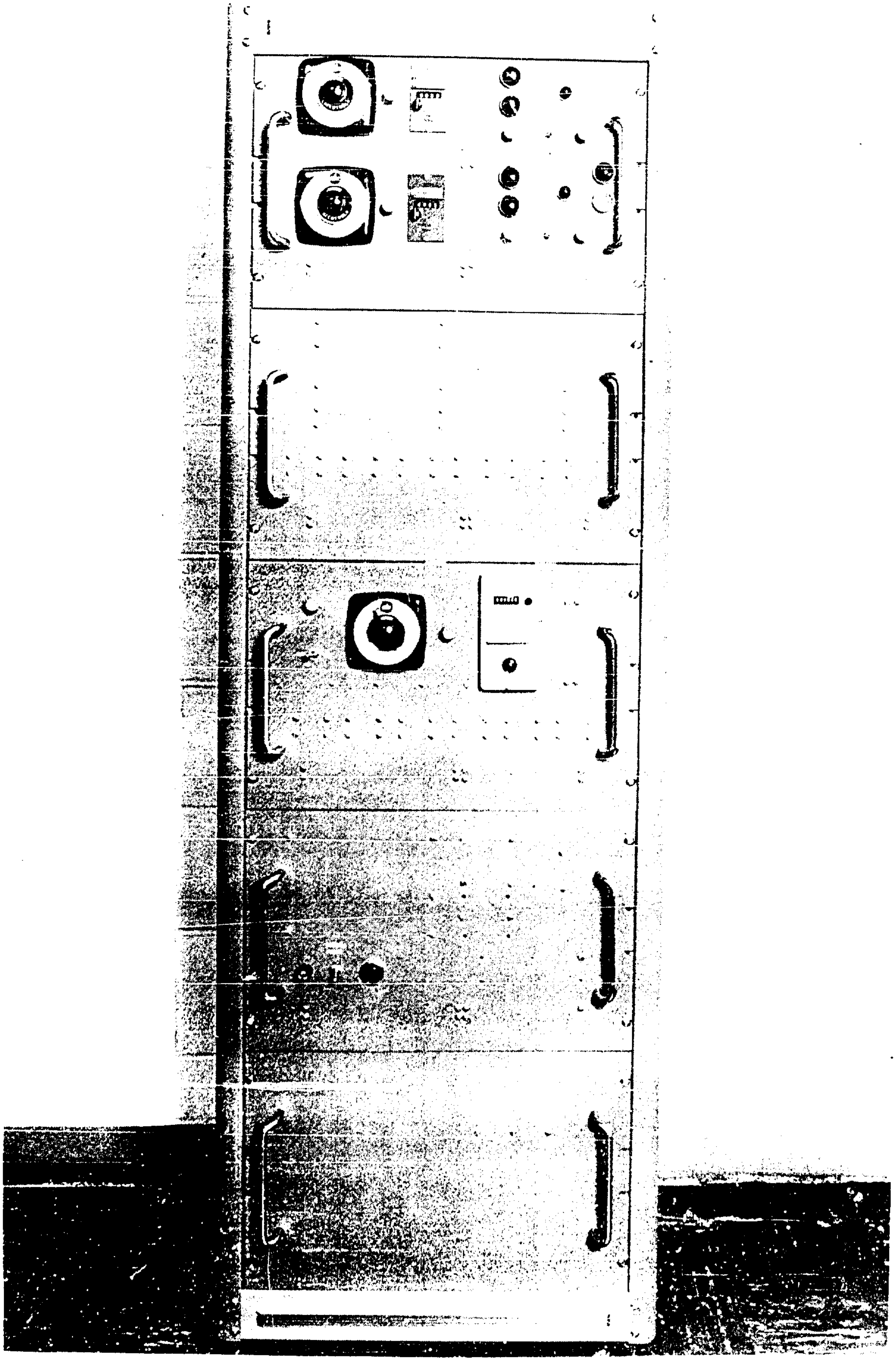
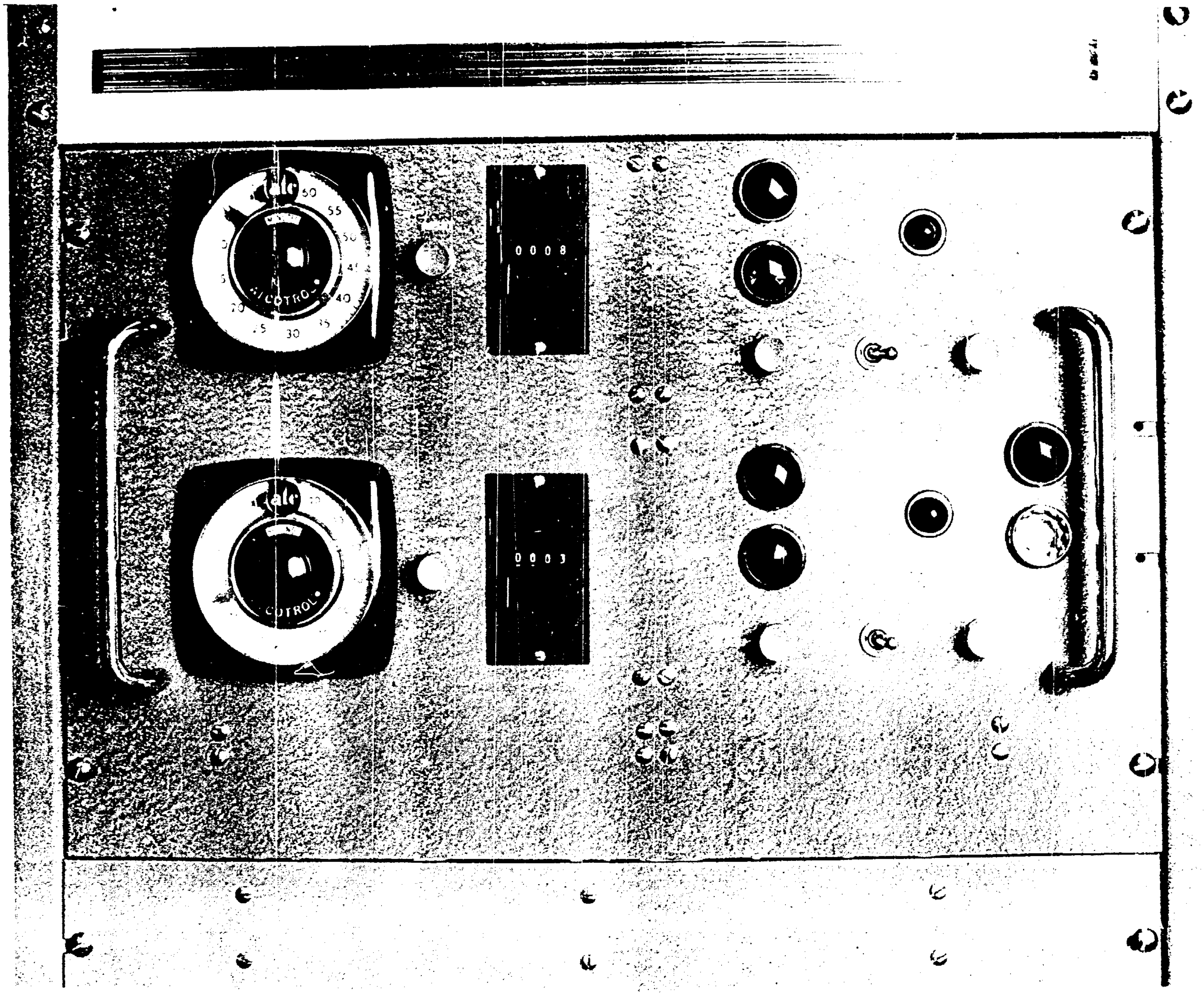


Photo No. 11



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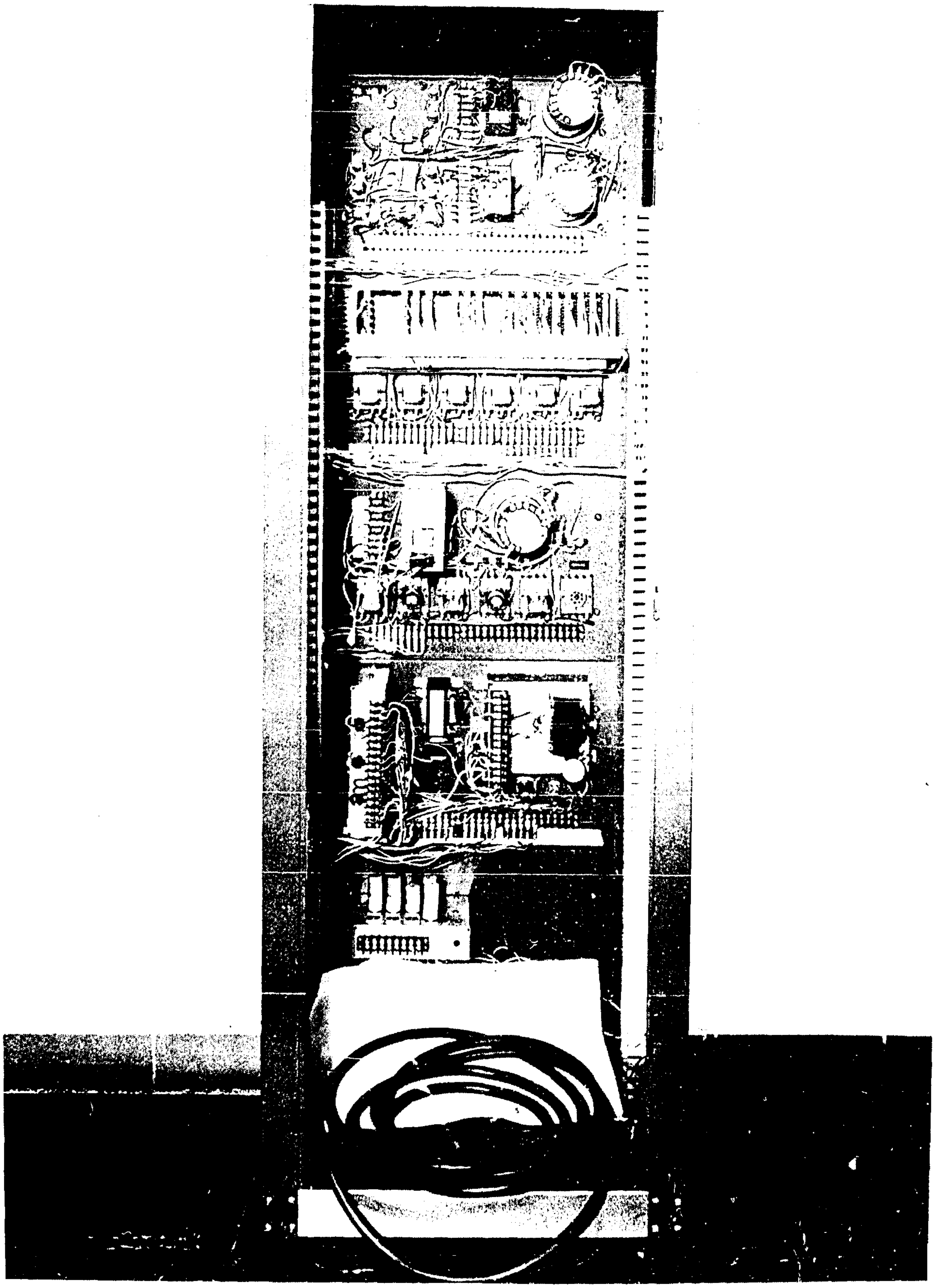

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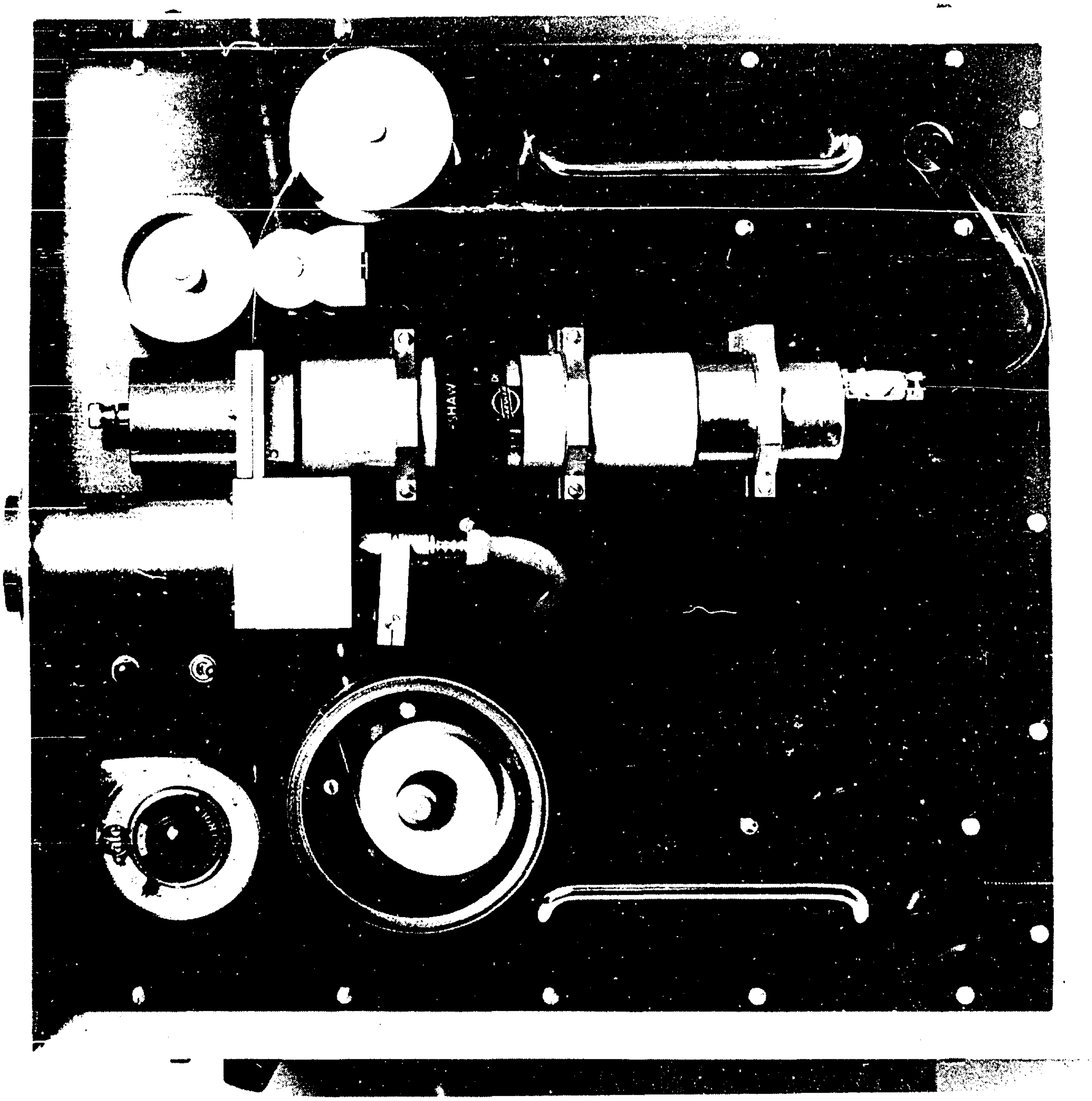

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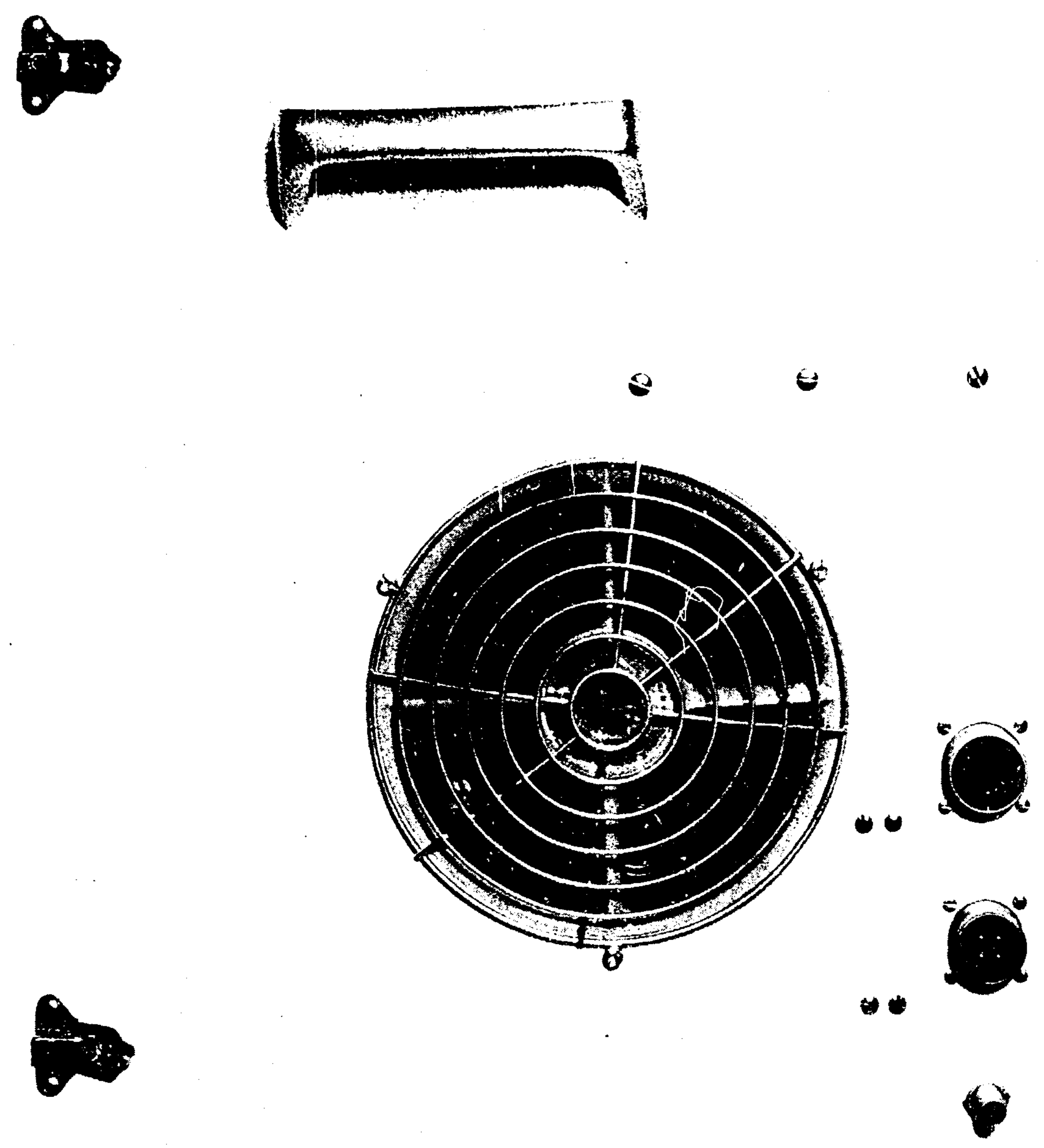

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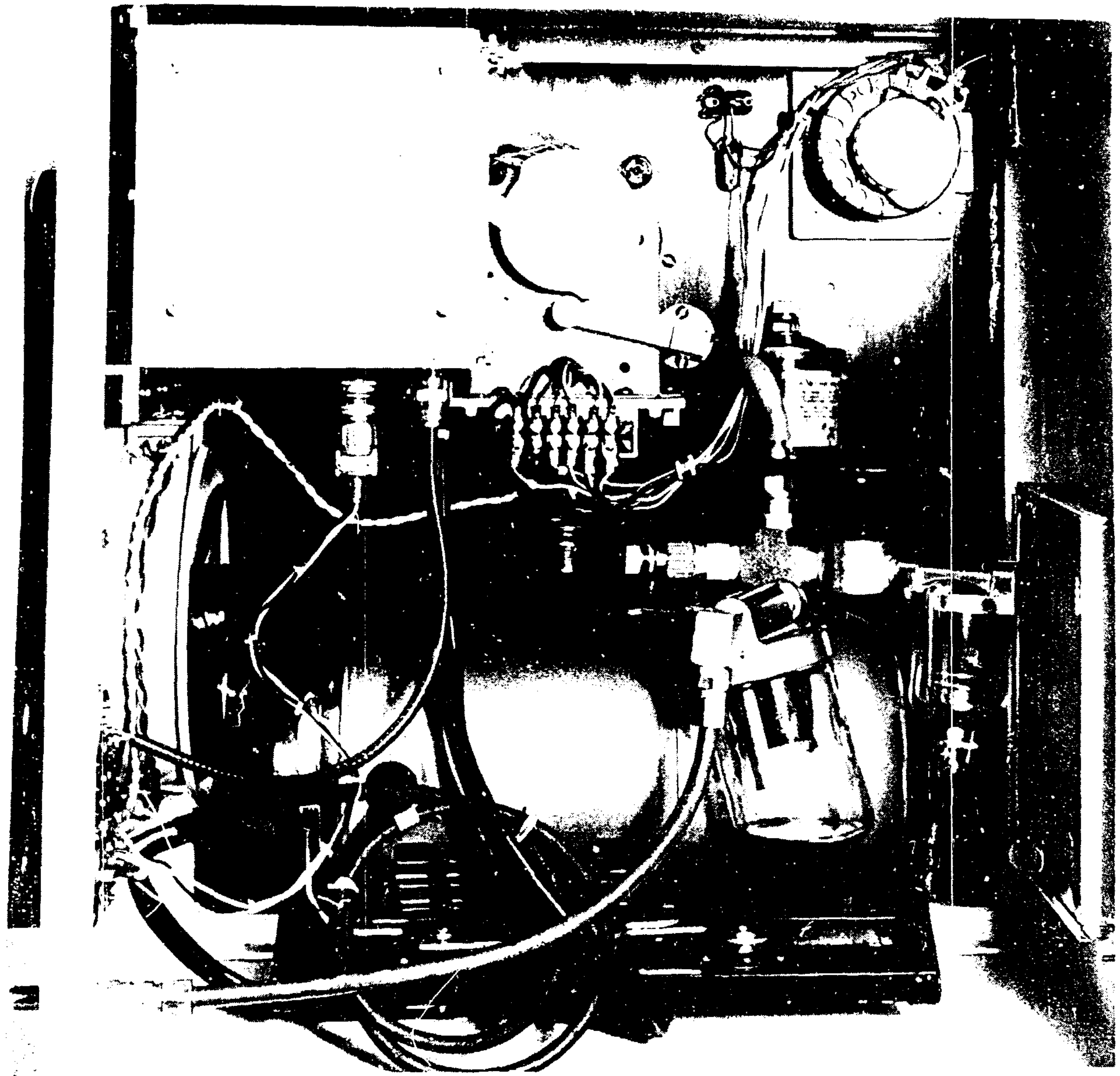

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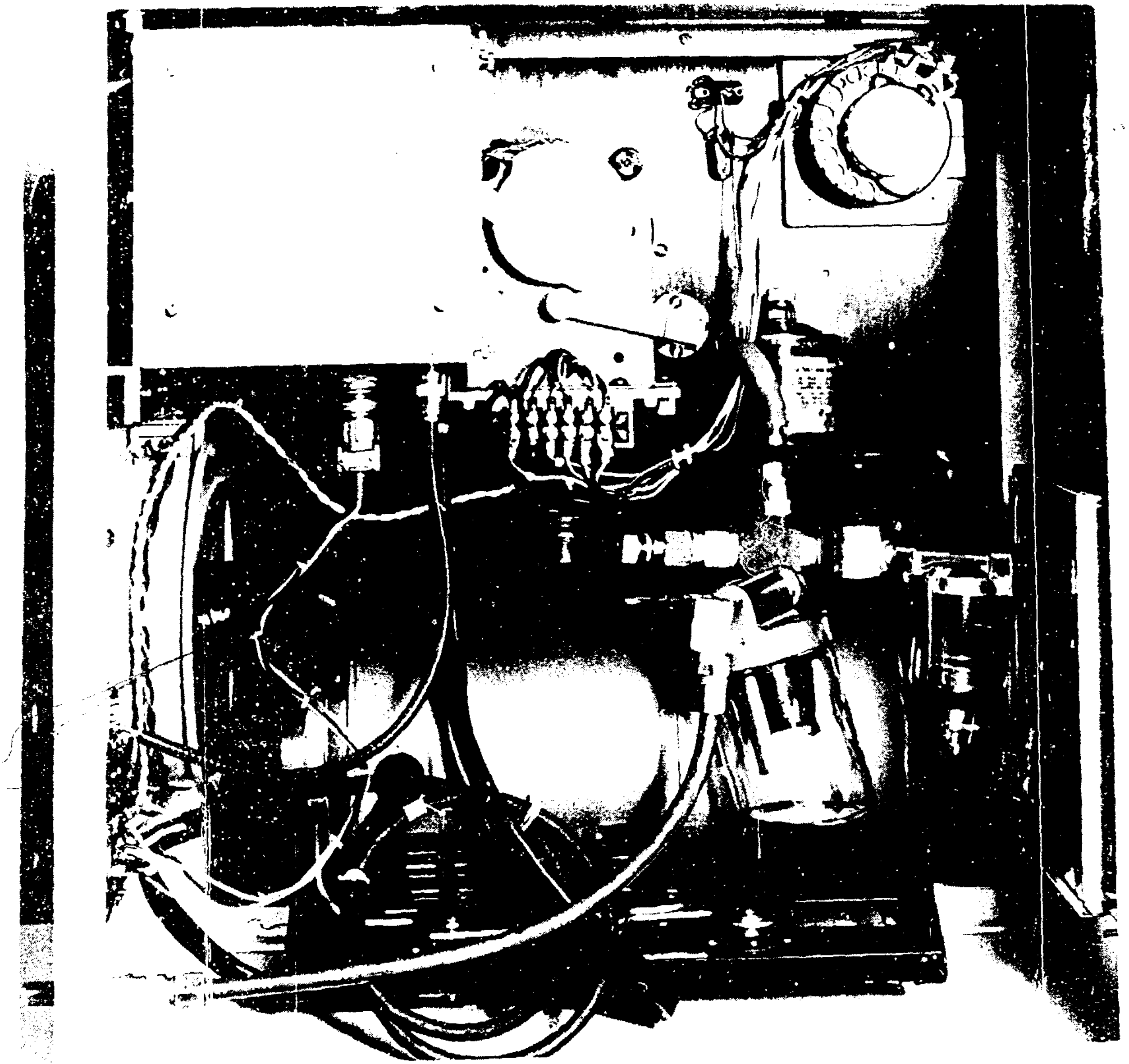

Photo No. 17

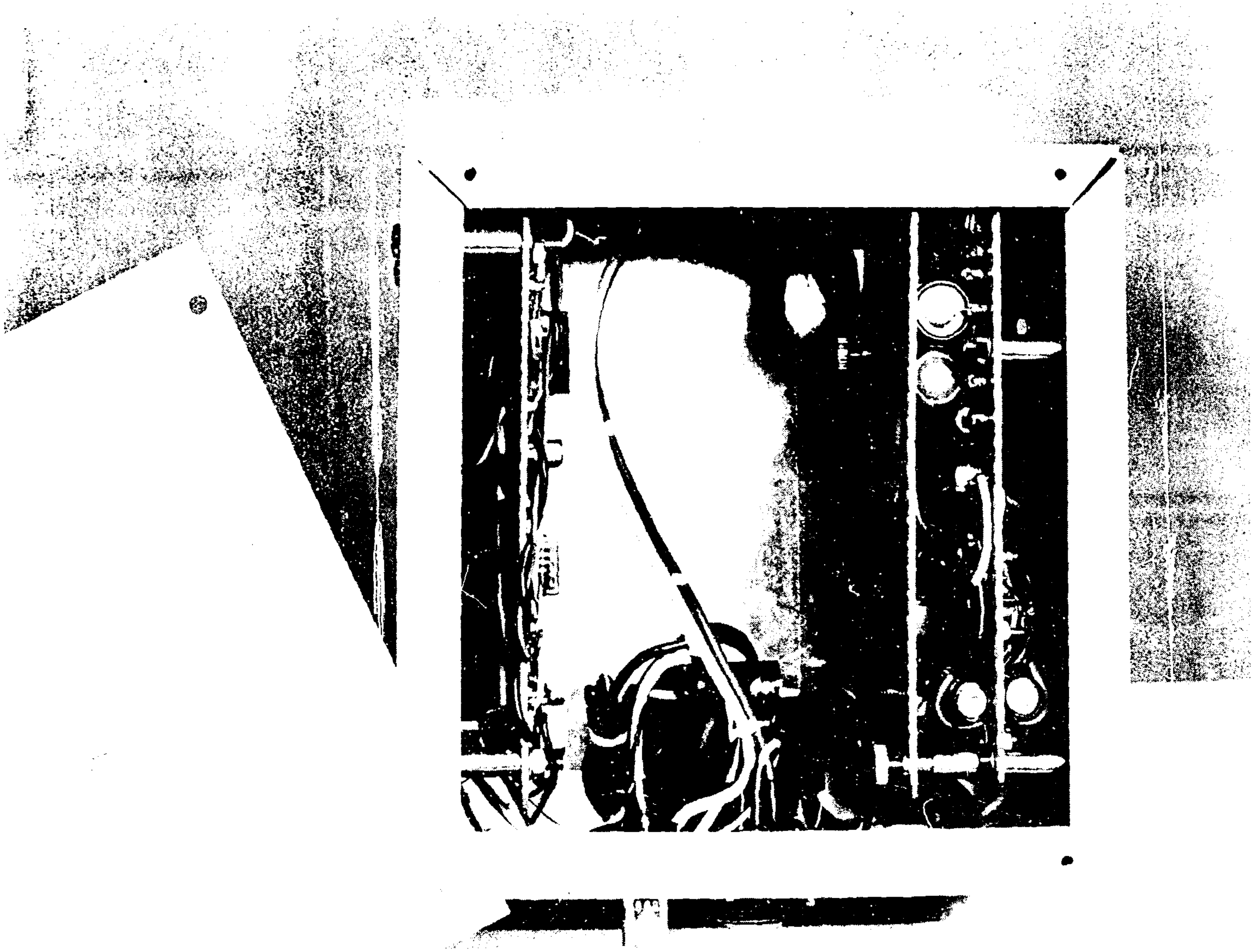

Photo No. 18